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ABSTRACT

This report, the fourth in a series, integrates findings from research pertaining to content area instruction of linguistically and culturally diverse learners (LCDLs). The focus is on the education of secondary-level English language learners (ELLs) within mainstream mathematics classes. The intent of this document is to give teachers and teacher educators a better understanding of how mainstream mathematics instruction can be designed and implemented to enhance academic achievement and learning for these students. Research for this report included an extensive search of National Clearinghouse for Bilingual Education (NCBE) bibliographic database, the ERIC bibliographic database, and various World Wide Web sites for information regarding effective curriculum and instruction, content standards, student assessment, teacher training, and education. (Contains 41 references.) (KFT)

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E-mail: *askncbe@ncbe.gwu.edu*
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Principal Investigator: Joel Gomez, Ed.D.
Interim Director: Minerva Gorena, Ed.D.

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GRADUATE SCHOOL OF EDUCATION AND HUMAN DEVELOPMENT

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Overview

This document is number four of a series of four reports prepared under contract by the National Clearinghouse for Bilingual Education (NCBE) in response to task order number D0003 for the U.S. Department of Education, Office of Bilingual Education and Minority Languages Affairs. In accordance with the task order requirements, this report integrates findings from research pertaining to content area instruction of linguistically and culturally diverse learners (LCDLs). Three key questions outlined in the task order are addressed:

- What does the relevant literature pertaining to content area instruction of linguistically and culturally diverse learners (LCDLs) contribute to the theory and practice of standards for LCDLs?
- What does the relevant literature pertaining to content area instruction of ELLs contribute to the theory and practice of measures of achievement, proficiency, and/or academic literacy for LCDLs?
- What does the relevant literature pertaining to content area instruction of LCDLs contribute to the field of promising practices in content area instruction for LCDLs?

The focus of this fourth report is on the education of secondary-level English language learners (ELLs) within mainstream mathematics classes. The intent of this document is to give teachers and teacher educators a better understanding of how mainstream mathematics instruction can be designed and implemented to enhance academic achievement and learning for these students.

Research for the report included an extensive search of the NCBE bibliographic database, the ERIC bibliographic database and various World Wide Web sites for information regarding effective curriculum and instruction, content standards, student assessment, teacher training and education.

In addition, the national content standards documents for mathematics (*Curriculum and Evaluation Standards for School Mathematics*) and three other core areas (Language Arts, Science, Social Studies) were analyzed to determine whether their theoretical bases were consistent with what educational research tells us is effective practice for ELL students.

Information was also collected through site visits[1] to a suburban high school that had implemented a team teaching approach for working with ELL students enrolled in mainstream classrooms.

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[1]Site visits were conducted in May 1997.

Introduction

After almost two decades of effort, challenging academic standards are now in place in many of our nation's schools. Content and curriculum standards explicitly designed to address educational excellence have been developed and implemented — or are in the process of being developed and implemented — at the national, state and local levels, in elementary and secondary schools, and across most disciplines (Chris Green & Solis, 1997).

A central focus in the move toward standards-based learning has been the question of how to ensure equal access to a quality education, with particular attention paid to the special needs of linguistically diverse English language learners (ELLs). In comparison with their English proficient peers, students who are in the process of learning English face a more difficult task in meeting a common set of learning standards. Not only do these students have to focus on the cognitive demands of a given class or assignment — learning new subject matter, procedures and tasks — they have to do so while learning new vocabulary, linguistic structures, and academic discourse. Moreover, ELL students at the secondary level may have significant gaps in their prior education that influences their ability to meet the cognitive demands of the high school curriculum (McKeon, 1994).

In supporting equal access to challenging academic content, then, it is critical to implement educational practices that have proven to be effective for linguistically diverse students, and to hire teachers who are fully qualified to work with them. While ELLs in some schools receive sheltered or bilingual content instruction, many ELLs spend the majority of their time in mainstream classes that are not specially designed to meet their needs, with teachers who have not received appropriate training in the education of diverse learners (McKeon, 1994). The quality of the mainstream instruction they receive thus becomes a significant factor in whether these students succeed academically (Cornell, 1995).

If we expect ELL students to meet a higher level of academic success, it is necessary to consider the teacher behaviors and instructional approaches that will help make language and content accessible for them, to design preservice teacher education programs that include training expressly related to their education, and to implement those best practices and model curricula that mainstream teachers can use. The following sections discuss these issues within the context of mainstream secondary mathematics classrooms and the standards for mathematics education. Concluding sections examine the characteristics of fair and meaningful assessment, and effective mainstream teacher preparation.

Making Mathematics Accessible to the English Language Learner

Emphasize Problem Solving in Authentic Contexts

Efforts to reform the teaching of mathematics were given a push in 1989 with the release of *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics or NCTM). This and other reform documents criticized the mathematics curriculum and the way in which mathematics was taught. Standards developers advocated moving away from the traditional focus on acquisition of facts, technical skill and textbook-based instruction to a curriculum of hands-on activities and intellectually challenging problems. According to the report,

> [t]raditional teaching emphases on practice in manipulating expressions and practicing algorithms as a precursor to solving problems ignore the fact that knowledge often emerges from the problems. This suggests that instead of the expectation that skill in computation should precede word problems, experience with problems helps develop the ability to compute. Thus, present strategies for teaching may need to be reversed; knowledge often should emerge from experience with problems. Furthermore, students need to experience genuine problems regularly. A genuine problem is a situation in which, for the individual or group concerned, one or more appropriate solutions have yet to be developed (National Council of Teachers of Mathematics, 1989).

The notion that students will develop their mathematics abilities to a higher degree when motivated by authentic problems is supported by research (McLaughlin & McLeod, 1996), and has led to changes in instructional practices within some school districts. Below, two classroom vignettes demonstrate how problem solving in authen-

Vignette

I. Applying Mathematical Skills to Solve Problems

In a seventh grade classroom in Salinas, California, Latino students are huddled over a model of a bridge that they have constructed. They are trying to determine the proportions needed to build a slightly different bridge, [one that is] three-and-a-half times larger.

By focusing instruction on such themes as architecture (bridges), astronomy (space), and statistics (baseball), mathematics is taught in highly contextualized situations where the focus is on the acquisition of conceptual knowledge, problem solving, and the application of mathematical skills to concrete problems (McLaughlin & McLeod, 1996).

Vignette

II. Developing Creative Mathematical Problem Solving

Ms. Simis' eighth grade math class includes 15 LEP (limited English proficient) students. They speak a number of primary languages and have varying degrees of oral English proficiency, but have sufficient English reading and writing skills to participate in an all-English environment.

Ms. Simis conducts the class in English. The next lesson is about spatial math. At the start of the lesson, the teacher tells the students that she once found this aspect of mathematics to be difficult. With patience and persistence, she says, the students will understand it just as she did. Ms. Simis asks students to design three-dimensional buildings using Legos, following a number of specific constraints: preserve the right and front view but extend the building.

As she introduces the lesson, she asks a student to restate her constraints and instructions; after the second attempt he does so. She then suggests that student "experts" in each group assist other students. The experts are not necessarily the most accomplished; Ms. Simis selects students who have struggled to learn something, so they can help others who are struggling.

The students use Lego blocks to model the building, and then draw the structure from all angles on special paper. As they extend the buildings in new ways, Ms. Simis calls these innovations to the attention of the class. When one group says, "We're finished" she challenges, "Now solve it another way" (Berman et al., 1995).

tic contexts has been used to improve learning for students from diverse cultural and linguistic backgrounds.

Encourage Development of Critical Thinking Skills

The shift in focus on the part of the mathematics community parallels current thinking about how to best educate ELLs. Padron (1993), for example, argues that the traditional notion of educating disadvantaged students in basic skills before exposing them to more challenging academic material has led to what they term "learned helplessness" or limited mastery of cognitive skills. For ELL students, a basic skills mastery approach can result in an inability to solve problems, to reason effectively, and to develop other higher-order thinking skills. Effectively teaching mathematics content to ELLs requires instructional settings and situations — such as those described in the above vignettes — where students are engaged in solving interesting, real-life problems that encourage critical thinking along with basic skills development and practice.

Teach the Language of Mathematics

Command of mathematical language plays an important role in the development of mathematical ability.

Mathematics courses can provide the necessary experiences for ELL students to acquire higher order thinking skills and mathematical competencies while also improving their communicative abilities in English. For such learning to occur, though, students need ample opportunities to hear math language and to speak and write mathematically. NCTM guidelines explicitly address this issue by directing teachers to orchestrate problem solving and other classroom discourse in a manner that encourages mathematical literacy (Buchanan and Helman, 1993). The guidelines recommend that teachers pose questions and design tasks that engage students' thinking, and ask students to clarify and justify ideas orally and in writing (National Council of Teachers of Mathematics, 1989).

NCTM guidelines and the research on language learning point out that mathematics discourse and syntactical structures have a number of features that make it difficult for ELLs to gauge meaning, such as the use of symbols and technical language, and the lack of redundancy or paraphrase to assist in understanding. Statements and questions are often written in the passive (e.g., *ten (is) divided by two*), and there is no one-to-one correspondence between mathematical symbols and the words they represent. For example, if translated word for word, the algebraic expression *the number a is five less than the number b* might be recorded as $a = 5 - b$ rather than the correct translation, $a = b - 5$. In the example, *Five times a number is two more than ten times the number*, students must understand how key words relate to each other, that *a number* and *the number* refer to the same quantity (Corasaniti Dale & Cuevas, 1992).

The language of mathematics also includes vocabulary specific to the field, such as *equation* or *algebraic*, as well as everyday vocabulary that has different meanings when used in mathematical contexts, such as *positive* and *negative*, *table* and *irrational*. Strings of words, like *measure of central tendency* and *square root* create complex phrases with specific meanings. Mathematics operations can often be signaled by more than one word or phrase; for example, *add, plus, combine, sum,* and *increased by* all indicate addition (Corasaniti Dale & Cuevas, 1992).

Students who are learning English must struggle with these many discourse rules and anomalies. Mathematics teachers who work with ELL students need to employ a dual approach, incorporating instruction on the mathematical language related to the particular concepts being taught along with the concepts themselves (Corasaniti Dale & Cuevas, 1992).

Create Language Supportive Classrooms

Journal writing offers ELLs the opportunity to practice and develop their emerging mathematics discourse skills.

Orchestrating classroom discourse with ELL students requires more than knowledge of the intricacies of mathematical language; it demands that teachers create classroom environments and instructional situations that support and promote students' linguistic and conceptual development. For example, in working from concrete problem solving situations to more abstract context-reduced ones, students can begin manipulating mathematical language by writing their own word problems drawn from their mathematical experiences and sharing them with other students.

Asking students to use journals to explore different strategies for solving mathematical problems, and to shape and refine their ideas is another useful strategy. Journal writing in mathematics classrooms allows students who may be too shy or intimidated to orally communicate their ideas to "speak" freely without concern for grammar or style. In their journal, students can summarize and relate ideas, clarify concepts, and review topics. They can describe strategies, accomplishments or frustrations, and express positive or negative emotions (Bagley & Gallenberger, 1992).

The following ideas for mathematical journal writing, though not specifically intended for ELL students, would be productive with these students. In some instances, native language use could be encouraged; in others, students could be asked to write in English to practice working with mathematical vocabulary and linguistic structures such as those specified in the previous section.

Prompts for Mathematical Journal Writing

(1) Construct a word problem about [this] picture that can be solved mathematically. Share your problem with a partner and solve it.

(2) What is the most important idea you've learned in algebra this week and why?

(3) Write a paragraph containing as many of these words as possible:_____

(4) List some things you must remember when answering this type of question or doing this type of problem (Bagley and Gallenberger, 1992).

The unit on mathematical probability described next — though, again, not specifically designed for ELL students — incorporates practices found to be effective with second language learners. By integrating reading and discussion with mathematics content, this type of unit supports the development of academic language skills and encourages greater depth in students' understanding of the topic.

Integrating Reading into a Unit on Probability

1. Students are given a written survey in which they are asked to make guesses about the probability of certain events. Through discussion, the teacher elicits students' understandings of probability and encourages questions to guide them in further exploration of the topic.

2. Students then examine the historical events that led to the invention of probability by forming pairs to read selections on probability. In pairs, students take turns reading and then stopping to pose questions and discuss the ideas presented. This "say something" strategy promotes social interaction between students, which supports their efforts to work out a meaning for the text. It also encourages them to take ownership for their reading/learning experiences and promotes an inquiry orientation to learning. Moreover, such a format works well for ELL students who may have difficulty reading textual materials on their own. By working with a partner, they are given extra support for developing both reading skills and their knowledge base on probability.

3. In follow-up exercises, the teacher asks students to put the historical information in their own words, make connections to the present, or discuss what piqued their interest while reading. By focusing on gaming in history, students can begin discussing various games in which probability plays an important role. ELL students who may have experience with different games can share these with the class at this point.

4. As the teacher begins introducing the technical aspects of probability, students review newspapers and magazines for everyday uses of probability and record these instances on note cards that can then form the basis for a discussion on how probability is interpreted in everyday usage (Siegel & Borasi, 1992).

Connect Mathematics to Students' Background and Experiences

NCTM guidelines include a recommendation for teachers to utilize the cultural and educational background knowledge of their students as a way to help them learn mathematics and make connections to other academic fields (Buchanan & Helman, 1993). Cognitively Guided Instruction (CGI) is an approach to mathematics teaching that supports the NCTM standards by encouraging teachers to use the prior knowledge

and developing mathematical thought processes of their ELLs in structuring lessons and curricula. CGI operates from the following premises:

(1) Teachers must know how their students mentally organize mathematical content.

(2) Instruction should focus on problem solving.

(3) Teachers should determine what their students are thinking about the mathematical content studied.

(4) Teachers should design instruction based on their students' thinking (Secada, 1992).

A related focus of the NCTM standards is to connect instruction to students' real life experiences in a way that makes learning meaningful. Secondary-level students who participate in sports can learn to calculate their batting averages or race times; those who have after-school jobs can use their pay stubs to figure the percentages of their various withholding categories. Making learning relevant by connecting what happens in the classroom with the outside world has been shown to contribute to the academic achievement of ELLs and other less advantaged students (Buchanan & Helman, 1993). Such students need to believe that schoolwork makes sense for their current and long-term welfare; for this reason, classroom tasks that are intrinsically interesting, or that directly relate to their interests and identity have the best chance of success (McPartland & Braddock, 1993).

Similarly, attention needs to be given to the social and cultural contexts underlying the mathematical problems used in the classroom (Secada, 1992). In one intermediate algebra class, for example, students studying how increased consumption of electricity is linked to decreasing rates (and sometimes smaller electricity bills) learned that consuming more electricity often entailed using appliances only the wealthy could afford (e.g., air conditioners, pool filtration systems). Such an analysis, though rich in real-life problem solving, may serve to alienate ELL students from the curriculum since the experiences highlight class distinctions already very apparent to many of these students (Secada, 1992).

Vary Instructional Methods

A final caveat from NCTM advises teachers to provide students with opportunities to learn in different ways, through individual, small group and whole class work

(Buchanan & Helman, 1993). Research on effective instruction for ELL students (August & Pease-Alvarez, 1996) similarly emphasizes the importance of using a variety of methods tailored to students' needs, including direct instruction, guided discovery, cooperative learning, and computer-assisted learning. Which instructional methods are selected depends on lesson goals and objectives, learner characteristics, level (s) of English language proficiency, and available resources.

ELLs learn best when instructional methods and approaches match their individual abilities and learning styles.

By using multiple approaches and considering individual learning styles and preferences, teachers can meet the needs of a wider variety of students (Reyhner & Davison, 1993; August & Pease-Alvarez, 1996). For example, traditional mathematics texts and materials tend to present abstract theories and verbal information. Studies of American Indian students, though, indicate that they perform better academically when taught through visual and tactile modes of learning. Developing a multi-sensory, activity-centered mathematics curriculum is one of the ways to address these types of learning style differences and support higher achievement in mathematics (Reyhner & Davison, 1993).

ELL Assessment within a Mathematics Program

Critical to the development of a student-centered and intellectually challenging curriculum for English language learners is the implementation of an authentic and meaningful assessment plan, one that:

- has a specific and clear purpose;
- incorporates student educational experiences, parents' literacy and other student background information;
- assesses content knowledge and abilities in English and the native language;
- includes assessment of content knowledge and language proficiency; and
- uses a diversity of measures, including portfolios, observations, anecdotal records, interviews, checklists, and criterion-referenced tests (August & Pease-Alvarez, 1996).

Many of the attributes listed above are reflected in the performance assessment criteria developed by local schools and districts, and described in the *Guide to Performance Assessment for Linguistically Diverse Students* (Navarrete & Gustkee, 1996). The Guide suggests, for example,

- *using alternative assessment procedures*, such as teachers' observations, students' self-appraisals, and parents' observations of their child's progress, and

- *designing alternative assessment tasks*, including exhibits, dramatic renditions, interviews, and writing samples.

Alternative assessment, because it requires students to perform authentic academic tasks similar to those originally used to teach the material, is considered a valid means of measuring student achievement. To assess mathematics proficiency, for example, students may be asked to develop a series of graphs based on student characteristics, to run a school store, or pretend to play the stock market. One of the appeals of alternative assessment is that it is continuous, allowing the teacher to track student progress toward meeting instructional objectives throughout the school year. Typically, student responses to alternative assessment tasks are organized in a portfolio designed to meet their individual needs and interests (Chamot, 1993).

The *Guide* (Navarrete & Gustkee, 1996) recommends a number of other techniques for improving assessment of ELLs in content area settings, such as:

- incorporating familiar classroom material as a stimulus to assessment tasks (quotations, charts, graphics, cartoons, and works of art);

- including questions for small group discussion and individual writing;

- mirroring learning processes with which students are familiar, such as the writing process and reading conferencing activities;

- allowing extra time to complete or respond to assessment tasks;

- designing administration procedures to match classroom instructional practices, simplifying directions in English and/or paraphrasing in the student's native language; and

- permitting students to use dictionaries or word lists.

Implementing assessment approaches that accommodate students' varied learning styles and backgrounds gives assessment greater validity and usefulness (Farr & Trumbull, 1997).

Preparing Mainstream Teachers to Work with ELL Students

Moving toward standards-based mathematics education for ELLs means adopting the types of curriculum and assessment practices described here, practices that have shown to be effective for second language learners. At the same time, effectively preparing teachers to implement these practices requires a substantial shift in the way in which they are taught, and the content of the courses they take. In an effective program of teacher education, all aspects of the coursework and field experiences — not just one or two courses — would involve preservice teachers in developing the skills and knowledge necessary for successful practice in diverse classrooms. A comprehensive, focused and multiculturally-infused curriculum would give preservice teachers ample opportunities to observe effective teachers in multicultural and multilingual environments, to reflect with their peers and collaborating teachers on their developing skills and cultural competencies, and to incorporate exemplary practices into their own classrooms (Chisholm, 1994).

Developing cultural understanding is an integral part of a successful teacher education program.

The essential features of an effective curriculum are suggested by Chisholm's work on teacher preparation (1994). She offers the following list of teacher competencies:

- a repertoire of methods and skills for adapting instruction to the needs of ELL students;
- alternative strategies for assessing student progress;
- a sound basis in testing methods, interpretation of test results, and ethnographic and observational techniques;
- ability to recognize cultural bias in tests and to use valid and culturally sensitive assessment measures;
- proficiency in assessing software for the accuracy of its cultural content as well as for its educational merit;

- ways to incorporate differences in cognitive and learning style into classroom instruction;
- understanding of cultural differences; and
- information on the contributions of linguistically and culturally diverse peoples to the content areas (Chisholm, 1994).

Chisholm adds that it is important to evaluate the cultural and academic competencies of preservice teachers in the same way that ELL students are evaluated — by involving them in multiple opportunities and a variety of tasks (1994).

Some of these same ideas were implemented as part of a training program initiated in the Chicago Public Schools. The program, designed to enhance the instructional competencies of mainstream teachers working with diverse learners, included the following set of training topics:

Issues Mainstream Teacher Education Programs Need to Address

- Adapting mainstream lessons and materials to meet the needs of ELL students
- Assessing and grading ELL students
- Distinguishing between language difficulties and learning problems
- Incorporating ESL methods into the mainstream classroom;
- Making academic English more comprehensible by teaching specific learning strategies
- Managing multi-language level classrooms
- Using cooperative learning strategies to encourage interaction between ELLs and native English speaking students
- Working with teaching assistants (Sakash & Rodriguez-Brown, 1995)

Other researchers (Farr & Trumbull, 1997, among others) recommend a similar set of curriculum features for teacher education programs, emphasizing, in particular, the important role of understanding cultural and linguistic differences in learning.

Conclusion

By setting challenging standards for mathematics education, we are assuming the responsibility for giving all students every possible assistance in achieving those standards. Designing a curriculum for mathematics education that incorporates problem solving and critical thinking, mathematics discourse, and authentic assessment is an important and necessary first step. Ensuring the implementation of that curriculum is equally important. To do so means defining new and rigorous standards not just for our students, but also for our future teachers. It means providing preservice teachers with the resources to enhance their own learning and content knowledge, along with their awareness of the challenges and opportunities presented by diversity. Only then can we expect to be successful in implementing a program of education that meets a broader range of students and offers success to all.

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Resources

Content Standards for Mathematics

Below is a listing of additional resources related to mathematics education and standards, and the education of diverse learners. Some of these were developed after this report was written.

Mathematics Education Resources on the World Wide Web. (1999). D. L. Haury & L.A. Milbourne, ERIC Clearinghouse for Science, Mathematics, and Environmental Education.<www.ericse.org>

National Centers for Information on Standards-based Curricula:

- Mathematics Curriculum Center, K-12 <www.edc.org/mcc>
- Elementary School <www.arccenter.comap.com>
- Middle School <www.showmecenter.missouri.edu>
- Secondary <www.ithaca.edu/compass>

Principles and Standards for School Mathematics, Discussion Draft. (1998). National Council of Teachers of Mathematics.<standards-e.nctm.org>

Selected Resources from NCBE's online library

www.ncbe.gwu.edu

Developing Target Second Language Skills through Problem-Solving Activities in Mathematics. (1997). L. Radford, J. Netten, & G. Duquette.

The Effects of Calculator Use in Middle Schools on Limited English Proficient Students' Problem-Solving Achievement in Mathematics, Panel Discussion. (1993). H. Waxman, S. L. Huang, S. E. Williams, & J. V. Copley.

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ESL Math and Science for High School Students: Two Case Studies. (1993). G. Spanos.

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About the Author

Kris Anstrom is Project Director of Project Accelerated Literacy at The George Washington University, and formerly an Information Analyst with the National Clearinghouse for Bilingual Education at The George Washington University. She has authored and co-authored several NCBE *Directions in Language and Education* and has contributed to various NCBE publications on issues related to the education of language minority students. Ms. Anstrom served as a training and research specialist with the Multifunctional Resource Center for Bilingual Education at the University of Wisconsin-Madison. She holds a master's degree in Teaching English as a Second Language from the University of Washington and has taught ESL in public schools and at the university level.

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The George Washington University
WASHINGTON DC

National Clearinghouse for Bilingual Education
Center for the Study of Language and Education
2011 Eye Street, NW, Suite 200
Washington, DC 20006